CONTROLLING THE AIRPLANE AT TWENTY THOUSAND FEET

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HOW the airplane will sail at twenty thousand feet can be predicted with confidence. How the pilot will sail his ship at that altitude is quite another question. Each year has witnessed improved designs in ships, so that planes to-day climb easily to twenty-five thousand feet; whereas five years ago they rarely exceeded ten thousand feet. During the war the aviator was called upon to drive close enough to the trenches to use his machine gun and to rise to eighteen or twenty thousand feet for combat purposes. Machines assisting the artillery in range finding did not often work above eight thousand feet. The different types of work called for different types of machines. Perhaps we should say for different types of pilots as well. As some machines can not rise to great heights, so too some pilots are incapable of work at great altitudes. General Squier reports that 61 per cent of men examined for altitude work are capable of flying to twenty thousand feet or more; 25 per cent. should not fly above fifteen thousand feet; and 14 per cent. were inefficient above eight thousand feet.[1]

High altitudes impose new conditions upon both the man and the machine. Rohlfs, the holder of the American altitude record, tells us that on a summer's day, when people are sweltering in the heat, he experiences in his climbs a temperature of twenty-five degrees below zero, and a wind of from one to two hundred miles an hour. Of course, the air pressure is greatly diminished. Both pilot and airplane have to contend with greatly decreased temperature and air pressure as they rise. This necessitates certain changes in the machine and certain changes in the man. The carburetor and the water system both have to be adjusted to meet the new requirements. The heart rate, the respiration rate, the blood pressure have to be adjusted to keep the pilot's system working. As the pilot and the plane are a unit in the work they do it is of course as important that the machinery in one should be studied, understood and cared for as thoroughly as in the other.

A great deal of work has been done to select and classify the fliers. Each of the countries in the war had an Air Medical Service

[1]Aeronautics in the United States, 1918. George O. Squier, Proceedings of the American Institute of Electrical Engineers. Vol. 38, No. 2, p. 81.

as a part of their air forces. At Mineola, Long Island, many tests and experiments were made in the Medical Research Laboratory and their results published by the War Department, Air Service Division of Military Aeronautics. Much more, of course, must be done and will be done.

The effect of the lowered temperature upon the aviator has not been thoroughly studied. We do not know just to what extent his senses and his reaction are affected. Certainly there must be some modification of his abilities by the change. The reduction in atmospheric pressure has its greatest effect in the depletion of oxygen supply. The merely mechanical effect of reduced pressure does not seem to affect vital functions. It does, however, cause great discomfort. We must remember the fact that we live at sea level, in an atmospheric pressure of about fifteen pounds to the square inch, and that as we rise this pressure decreases. When we bring this to mind we recognize that nature has provided us with constitutions to resist this pressure. The balance between the pressure of our constitutions and that of the atmosphere is equalized. When we rise to eighteen thousand feet there is just about half the atmospheric pressure to be resisted. The most conspicuous effect is upon the eardrums. Just back of these delicate membranes is the eustachian tube running to the throat, and filled with air. Each time we swallow we open the tube which equalizes the pressure upon the eardrums. As we rise and the pressure in the tube becomes greater than that outside, one experiences a distinct pain which is relieved by swallowing. As an aviator descends quickly he finds it necessary to force the air into the tube against the drum by holding the nose and blowing gently: otherwise a quick descent would injure the drums. Next to the discomfort in the ear is the rather characteristic frontal headache. This is due to the change of air pressure in the sinuses.

The greatest discomfort and detriment are occasioned by the lowered oxygen tension. The pressure of oxygen on the membranes of the lungs is lessened and the blood receives a diminished supply of oxygen. This is all important. Oxygen is indispensable to the nerve tissues, to say nothing of all other tissues. The old saying, "No phosphorus no thought," is absolutely true if oxygen is substituted for the other element. In order to keep the tissues supplied with oxygen, when the supply is being diminished, nature resorts to some interesting expedients. The lungs seek a greater supply by deep respiration. The heart seeks to increase the supply by quickening the blood stream, the blood vessels co-operate, giving an increased blood pressure. The blood itself changes its constituency. The deepened breathing, the quickened heart, the heightened blood pressure are all brought about by stimulating brain centres which control these func-

tions. Should these centres not respond until the blood stimulating them is very depleted in oxygen the compensations would not occur promptly, and the aviator would collapse. For this reason these functions have been carefully studied.

Before the aviator collapses from any fault of his vital functions, he may become so inefficient in handling his controls that he wrecks his machine. In the so-called "rebreather tests" the psychologists would frequently remove the aviator because of incapacity to keep his attention on his work or to control his movements. This condition often occurred, as the man received less and less oxygen, before there was any threat of physical collapse.

Of course, any deterioration in the functions of the nervous system spells disaster to the flier. If we consider the central nervous system as artificially and roughly divided into three parts, one of these would be concerned with sense impressions which carry impulses to the brain and spinal cord, one would gather these impulses centrally, and a third would convey out-going motor impulses to muscles and glands. A study of the sensory nervous system with its end organs under varying conditions would be most valuable to the air man. For example, it seems that one's vision is somewhat better after ascending a few thousand feet. This seems to be due to the increased blood supply, especially in the choroid and retina of the eye.[2] But after rising to fifteen or twenty thousand feet the vision is distinctly impaired. Hearing under high altitude conditions does not *seem* to be impaired at all![3] It would be important to discover the effects of low oxygen supply upon tactual and kinesthenic senses as well as upon the somatic senses, as these play a part in getting the "feel of the ship."

The motor mechanisms are certainly greatly affected by altitude conditions. The loss of oxygen gives the muscles much the same effect as fatigue. I have noticed in the low air pressure chamber that the slightest expenditure of energy, such as gripping the stick hard, or pushing the rudder vigorously, or even moving around in my chair brought a quick, perceptible fatigue. Indeed, one may quickly exhaust his oxygen supply and become unconscious if he exerts himself at all vigorously, around twenty thousand feet. Not only do the muscles become easily fatigued, but muscular coordinations become very poor.[4] This is beautifully illustrated by experiments in handwriting. A few specimens of notes taken by a man in the low pressure chamber under conditions similar to altitudes of six, fourteen and twenty

[2]The *Journal* of the American Medical Association, Vol. 71, No. 17, p. 1394.

[3]The *Journal* of the Medical Association, Vol. 71, No. 17, p. 1398.

[4]Air Service Medical, p. 312 ff.

thousand feet are given on Figure 1. It will be seen that there is a progressive deterioration with decrease of air pressure. The lettering shows the effort required to control the pencil. The men could see the lines they made but found it most difficult to control the finger movements. I am inclined to think there are fluctuations in motor control so that for a moment or two the coordination is quite good and then becomes inaccurate again.

The French and Italian experimentalists early conceived the desirability of testing not simply sensory, or motor factors, but both of these and the central factors too. This they did by the well-known "reaction times" test, which consists in stimulating any sense, usually sight, hearing or touch, and recording the time it takes to make a movement in response to the stimulus; for example, if a light is flashed before the subject of the experiment and he moves his hand the instant he perceives the light, it requires about .19 of a second for the nerve impulse to reach the brain, to be directed to the motor nerves, to descend these nerves and contract the muscles of the hand.[5]

This is a very simple operation of the nervous system. It is almost as simple as a reflex action. It would seem that the most important factor, namely, the central processes, is not sufficiently prominent. A better type of test is one which obtains "discrimination time." In this test several different stimuli may be presented, the subject does not know which one is coming; also, he is required to make a certain type of movement for each type of stimulus. That means he must recognize the signal given and make the appropriate reaction. This involves much more brain activity. It is a far better test of mental alertness.

"A good pilot should feel entirely at ease in space. He should be able to recognize at once the slightest difficulties with his machine in any one of the three dimensions. He should possess fundamentally the skill of command to re-establish equilibrium at any instant, just as a cyclist on his bicycle, but with this difference, that there exists a slight space of time between the moment of the movement of control and that of the effect produced. It is necessary then to correct the movement made, and at that point is the delicate matter of making the movement with too much intensity, or, on the other hand, insufficient intensity.

"In a word, it is the instantaneous transformation of a passing sensation to precise muscular contractions, but of infinite variability, with the purpose of constantly reacting to the invisible movements of the atmosphere and with all the other difficulties which may occur. This capacity, as it seems to me, is, above all, the result of training. Repetition of the same movement results in the formation of a nervous center which commands all the muscles involved in the execution of these movements, and then of centers in the medulla, which become substituted for the brain, in a transformation of a sensation to a movement. This is the theory of reflexes.

"The formation of these reflexes varies with the temperament of each person. The rapidity of acquiring them constitutes what is called aptitude. But in so far as the pilot does not acquire this automatic feature of his

[5]Ladd and Woodworth, Elements of Physiological Psychology, p. 476.

not so much strain on my ears. this run.
so far 2,000 ft.
Series at 6,000 ft O.K little nervous at first on account of noise but soon got used to it.

Just feel a trifle bit dizzy at 14.000 otherwise O.K. series went along O.K. and my reactions seemed to be normal.

Feel dizzy otherwise O.K. reactions seem to be coming OK feel OK otherise have a peach of of of a headache.

Dizzy and groggy at 20000 ft had trouble seeing rudder to set it in neutral. somehow everything seemed black

Sharp pain in front of head at 6000 ft

FIG. 1.

The third entry was written at 20,000 feet "altitude."

movements, he will have to furnish in his work a sustaining effort of attention, a great effort of will, which may go so far as producing nervous fatigue."[6]

[6] "Physiology, Physical Inaptitude, and Hygiene of the Aviator," by Dr. Guilbert, of the French Air Service. Air Service Medical, pp. 128-29.

To obtain an insight into the quickness with which a man recognizes a signal and makes the correct response, a form of discrimination time test was used in the Medical Research Laboratory at Mineola. In designing the test I sought to make the reacting movements similar to those of the pilot. An aviator's seat and controls, consisting of the stick and rudder bar, were placed in a large, low air-compression chamber, and electrical attachments were made to those controls in such a way that the time of discrimination was registered on a tape in units of 1/36 sec. Also, the direction of the movements of the stick and rudder bar were likewise registered. Through a window of the chamber a card was displayed which indicated how the stick and the rudder should be moved. When a shutter dropped, exposing the card, the timing device began to run and continued until the subject had reacted with both stick and rudder. The reactions, of course, tell us only how quickly the man made his discriminating responses. They do not tell us *how* he made them. He may have jerked his stick and his rudder with great vigor in such a way that if he had been in a plane instead of a steel chest he would have turned forty somersaults. As a matter of fact some of the men occasionally threw their controls with violence when under low air compression. This trait would disappear as the pressure returned to normal. It was not a constant performance. It, of course, is a result of the muscular incoordination mentioned above.

In determining the quickness of discriminating reactions under reduced oxygen conditions. I was fortunate to have for my subjects six experienced psychologists and one very intelligent enlisted man. Two of the subjects could not complete the series of tests. Four out of the other five continued the tests until their reactions had become quite automatic.

The procedure in the experiments consisted in placing the subject in the aviator's chair, explaining the reactions desired and in giving a number of trial reactions to accustom him to the apparatus and his duties. When he felt at home in the conditions imposed upon him, and had learned the best way in which he could make his responses, the actual testing began. Each subject was given a series of fifty tests at a time, never more than this. Occasionally a man would take but one series in a day; the work was dependent upon the availability of the men for the hours of experimentation. Each man was given his tests until his time of reaction, the mean variations of the time and the per cent of errors he made, all indicated that he had become as quick and accurate as it was possible for him to be. A learning curve was plotted for each man as he progressed. When it appeared that he had reached his highest efficiency, the tests in the low air pressure chamber were given. In most cases, however, the

"altitude tests" were given before the learning curve indicated a complete disappearance of improvement.

In the "altitude" tests the subject was first given a series of fifty at sea level, then he was allowed five minutes rest while the air pressure was reduced to an equivalent of six thousand feet altitude. At this point another series of fifty tests was given, followed by another rest of five minutes while the pressure was again reduced, this time to an equivalent of fourteen thousand feet, again a rest and a series at twenty thousand feet, another rest and a second series under the same condition, again a rest and a third series under these conditions. Then, after the usual five minutes rest the pressure was increased to an equivalent of fourteen thousand feet and another series of fifty tests taken, then back to six thousand and a final series at sea level. The nine series would average about eight minutes per series. The compression changes would be made at an equivalent of one thousand feet per minute. One or two physicians accompanied the subject in the chamber during the test. They were supplied with oxygen by means of rubber tubes connected with tanks outside of the chamber. Occasionally they allowed some of the oxygen to leak into the chamber. To allow for this specimens of the air were taken at the beginning of the first series at 20,000 ft. under the low compression and again after the completion of the third series at that stage.

It will be seen that the situation does not exactly duplicate that of the flier in the plane. There is the absence of the high wind, of the great cold, and, of course, the excitement incident to danger. But the most important condition which affects the aviator physically, namely the low supply of oxygen, is the same in both situations. The sort of signals to which the aviator responds when in a plane; slight movements of the ship; the sounds from the engine; signals from other ships when flying in formation; or the appearance of a hostile plane are all very different from the signal cards. But the time of reaction to the signal, no matter what the signal is, is a physiological matter. The time of nerve conduction from sense organs to brain and thence to muscles should remain the same. It would appear then that the effects of low oxygen upon discrimination time in the compression tank should also be descriptive of discrimination times in actual altitudes.

The first subject, A., who took the "altitude tests," did so after going through twenty-three series of fifty tests each at sea level. He did not however reach the equivalent of twenty thousand feet owing to a leak in the oxygen supply. The charts Figure 2 give the results graphically. It will be noticed that his errors in reacting increased greatly during the first run and were very erratic. In the

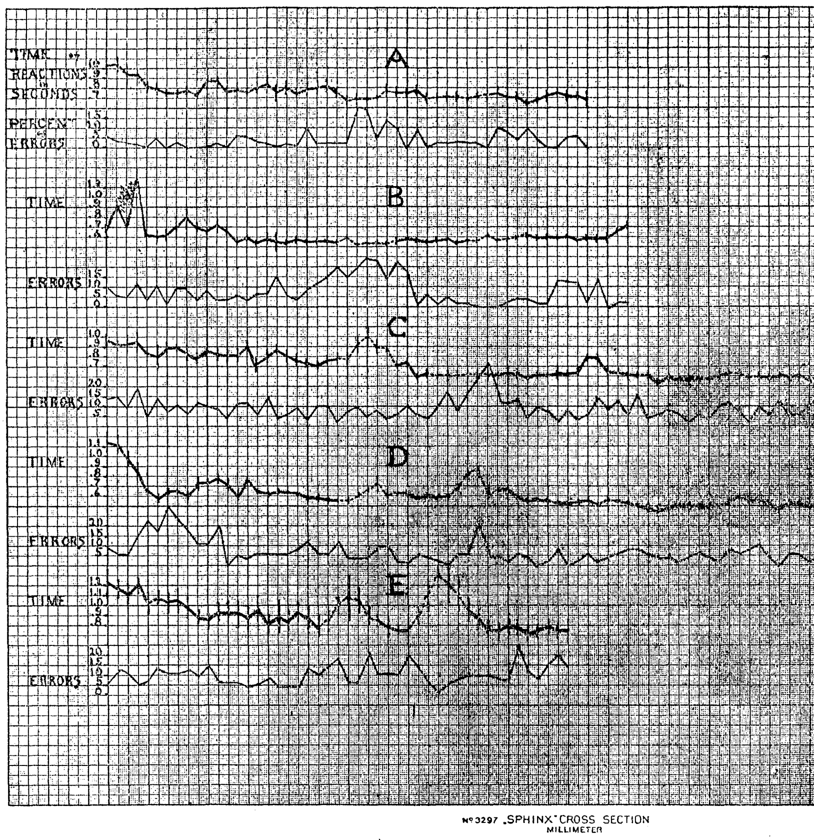

FIG. 2.

The heavy black line represents the average time required to move the controls in response to signals at sea level. The verticals intersecting it indicate the mean variations from the average. The dotted line gives the averages at "altitudes"; the first vertical indicating 6,000 feet, the next to the right, 14,000 and the three following approximately 20,000, then 14,000 and finally at 6,000.

The light line indicates the per cent. of errors made in the responses with the stick and the rudder.

The first "altitude" tests of both A and B show no increase in time required for their reactions, though both scored a larger per cent. of errors. In their second "altitude" tests their promptness and accuracy are quite as good as at sea level.

The learning curve for C and D is longer than for A and B. Two "altitude" tests, made before their reactions had become habitual, show deviations in the time, or error, records from their sea level averages. Their third set of "altitude" tests compare favorably with the sea level tests.

The time averages, mean variations and errors of E show that his reactions were not habitual. Oxygen depletion affected his time of response markedly.

second set of "altitude" series he appeared to be but slightly slower in his reactions, and much more accurate. The explanation of this given by the subject, who is a professor of psychology in a western university with many years' experience, is interesting. He felt that his "range of attention," his "field of attention" appeared to be narrowed when in low air compression. This he thought tended to inhibit distractions, leaving him freer to attend the stimuli. When he returned to sea level conditions he stated that the distraction of his surroundings was greater than under low compression.

This narrowing of the attention may explain a statement which several aviators have made to me concerning their flying at high altitudes. They said that it was easier to fly at these heights because your attention seemed to be on the ship and on nothing else. One naïvely remarked "the earth is so far away there's no use thinking about it." The situation is full of illusions, however, and what a man thinks he is doing when his field of consciousness is actually diminished cannot be trusted very much. When the series under the low compression during the second "altitude" tests are compared with the nine series taken at sea level three days later it appears that the altitude figures are lower than those for sea level. This can only mean that low compression does not affect this man in his quickness and accuracy of discrimination and reaction.

The next subject, B., had also been through twenty-three series of sea level tests before he was given his altitude tests. Like A., he made a great many errors during his first "altitude" runs, but his actual time and his mean variations from that time are not affected by altitude. In his second "altitude" series he made fewer errors but required slightly longer time than in the first set. Six days after the second "altitude" work, his eight *sea level* series give averages for time and mean variations just about the same as his second "altitude," though his errors increased. Here, again, it seems that low pressure and reduction of oxygen to values equivalent to the altitudes mentioned do not result in any appreciable lengthening of time or increase in errors for discriminating reactions.

The third subject, C., required many more practice series before his reactions became automatic. Comparisons of his first, second and third "altitude" runs show a considerable drop between the first and second in time but not in errors, while the third shows a more even distribution of errors and about the same time. Five series taken at sea level the day after the last "altitude" run show a slightly better performance, though insignificant in its difference.

Subject D., also, required a large number of tests before his time and errors reached their minimum. In his first two "altitude" tests

his time of reaction considerably lengthened with the decrease of air compression. In the second series the time is longer and the errors more erratic than in the first. After a number of days of testing the third "altitude" series shows very little increase in time and error over the sea level series which immediately preceded and succeeded it. However, a set of five series at sea level taken the next day show an improvement in both time and errors. This indicates that this subject had not yet quite reached his maximum efficiency. He was still improving upon his time slightly.

With the fifth subject, E., it was impossible during the time available to train him to that condition where his reactions were virtually automatic. This shows in the great number of errors he made, in the very wide mean variations from his time averages, and in the rather extreme length of time required by him for his reactions. In both of his altitude runs there is an increase in the reaction times corresponding to a decrease in the air pressure, a situation quite similar to the first two altitude runs of Subject D.

In attempting to interpret these results we must keep several things in mind. The first is that a man becomes accustomed, in some measure through experience, to altitude conditions. He learns the great secret of deep breathing and he learns to conserve his energy. Furthermore, he is not so disturbed by the symptoms of oxygen hunger and he has more confidence in himself. The more frequently he makes his responses to his signals the more automatic do his reactions become. They may, indeed, as Mr. Gilbert states, result in the formation of a nervous centre which commands the muscles involved in the reaction, "and then of centres in the medulla which become substituted for the brain in a transformation of a sensation to a movement." I question the formation of a centre in the medulla, but it does *seem* as though the higher centres of the brain relegated automatic movements to lower centres. In this case, as the men became automatic in their responses to the signals the oxygen depletion affected them less. Indeed, it would seem as though these lower centres with their simple functions are hardly affected under the conditions of the experiment.

Certainly the higher function of the brain are profoundly affected. This appears from the introspection of the men. They all experienced dizziness and a tendency to vertigo, most of them becoming drowsy and only retaining their control of themselves by concentrated effort. The temptation to doze off is very great. Notice in the specimens of handwriting the misspellings and the repetition of a word, which were undetected while the man was writing. These lapses would never occur if the mind were alert. Obviously the mind is not alert. The best demonstration of that is to experience the change which

comes over one when he has an opportunity to take oxygen when undergoing such an experiment!

The introspections written by the men during the tests are incomplete. It was feared that any special directions might burden them and distract them from the reaction work itself. For this reason they were told to jot down simply those things which occurred to them by way of observation concerning their feelings, emotions, thoughts, actions, as well as the progress and condition of the tests. However, from the notes made some interesting material is available. Three of the men noticed the unique effect of low oxygen upon their moods. Two felt irritable at lower "altitudes," but quite exhilarated at the higher "altitudes." One simply stated that he felt "just fine," though he was suffering from dizziness and a painful headache. The exhilaration somewhat resembles the feeling of well-being incident to an alcoholic drink. Often it is nothing more than a sort of carefree mood. Five out of eight men whom I have tested in low compression noticed this and mentioned it on their own initiative. As one aviator said who had just returned from France, "I felt as though I didn't give a hang." The same idea was expressed more elegantly by a college professor who remarked that he still tried to do his best, but had a "feeling of happy indifference." This emotional condition is one of the most important things to be noted as the effect of altitude. It easily might inspire the aviator to attempt "stunts" his normal judgment would not permit. This carefree attitude, added to the awkwardness of movements and narrow field of attention, makes a splendid conspiracy for a crash.

The aeronautic engineers believe that they are still in the beginning of their science, though they have accomplished a very great deal. Each year witnesses new discoveries and devices. The airplane is being constantly perfected. Obviously, the air service medical experimentalists are at the beginnings of their science. Certainly it is as important as that of the engineers. Some recognition of this fact is conceded by the government efforts in the experimental laboratory and in the work of the flight surgeons. Probably nothing would promote the science of aviation more quickly than a shift of interest from the machine to the man.